

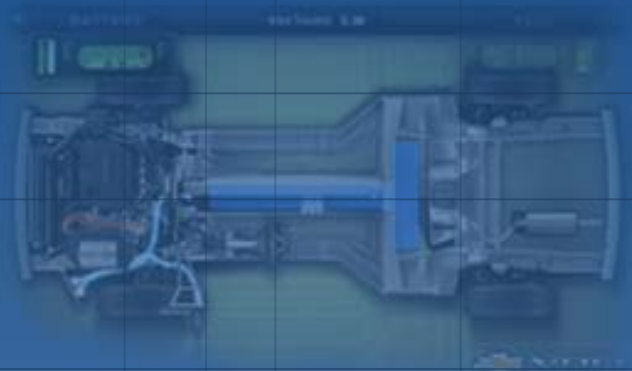
New Areas of Automotive NDE: Li-ion Batteries and Composite Materials

Leonid C. Lev

General Motors R&D

March 1, 2012

Houston, TX



Future of Automotive Transportation



OBAMA ADMINISTRATION Fuel Economy Standards In the year 2025

The fleet-wide average will be

 **54.5**  MPG

Consumers will have saved
\$1.7 TRILLION
at the pump over the
life of the program.

A family that purchases a new
vehicle in 2025 will save


\$8,200

in fuel costs when compared with
a similar vehicle in 2010.

Over the life of the program, the standards will:

Save  **12** billion
barrels
of oil.

Eliminate **6** billion
metric
tons
of carbon dioxide pollution.



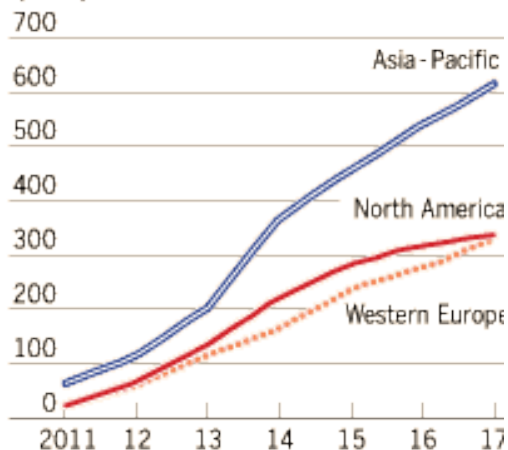
This program, together with standards already put into place by this
administration for Model Years 2011-2016, will result in significant
cost savings for consumers at the pump, dramatically reduce oil
consumption, cut pollution and create jobs.



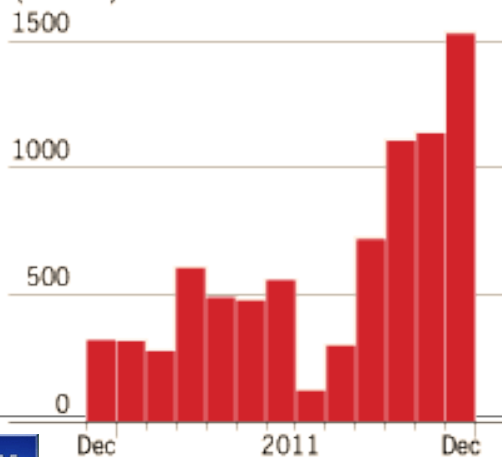
Future of Automotive Manufacturing

Electric cars

Forecast annual light-duty PEV sales, vehicles ('000)



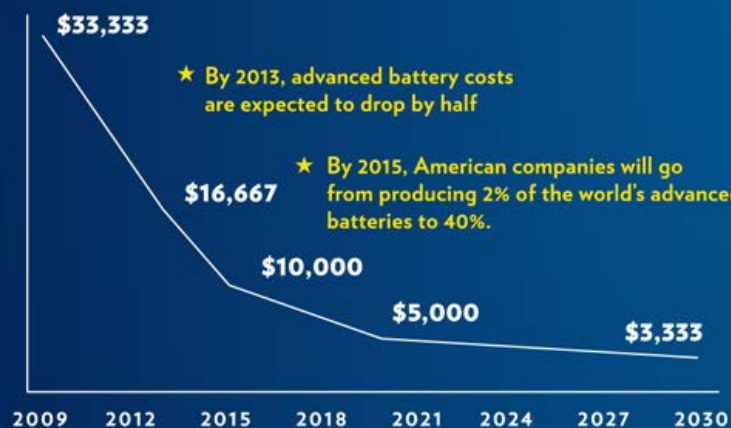
Chevrolet Volt unit sales (number)



Improving Transportation

The President has invested in making America a leader in the future of electric

Forecasted Cost of a Typical Electric-Vehicle Battery



The biggest cost of electric cars are their batteries

Goal: 1 million advanced technology vehicles on the road by 2015

Which would reduce oil consumption of about **750 million barrels** through 2030.

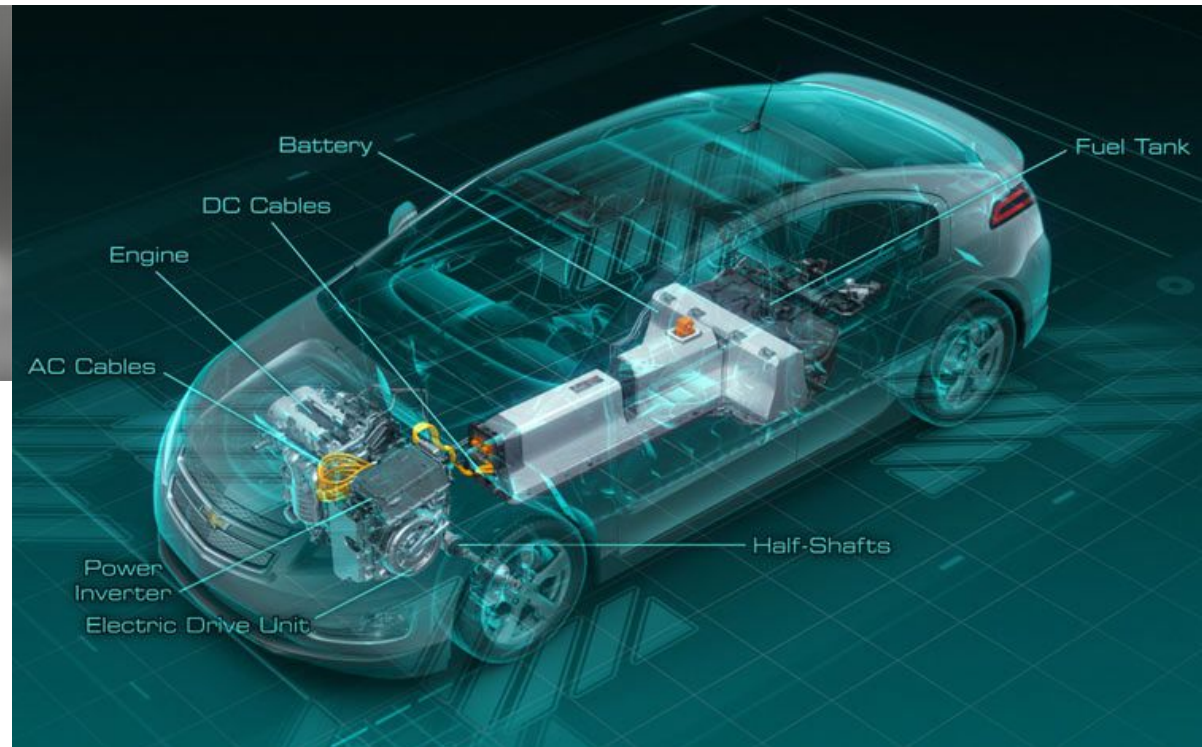
GM

Sources: Pike Research; company

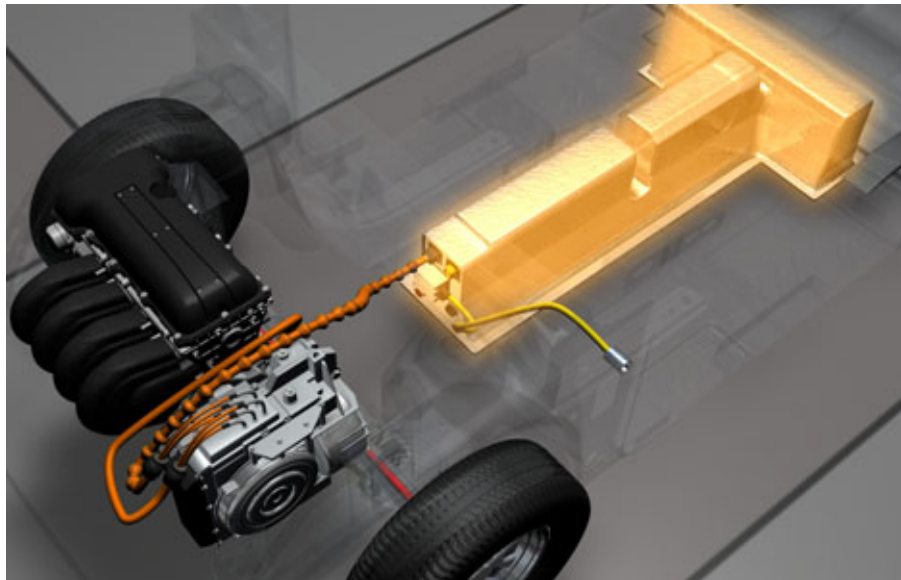
Future of Automotive Powertrain Technology: Chevy Volt

“The 2011 Chevrolet Volt is in the vanguard of the auto industry’s shift from the petroleum-based model...to the electrified model.

With its new Voltec propulsion system, GM...brings a unique approach...” [SAE, 2011]



Voltec Powertrain

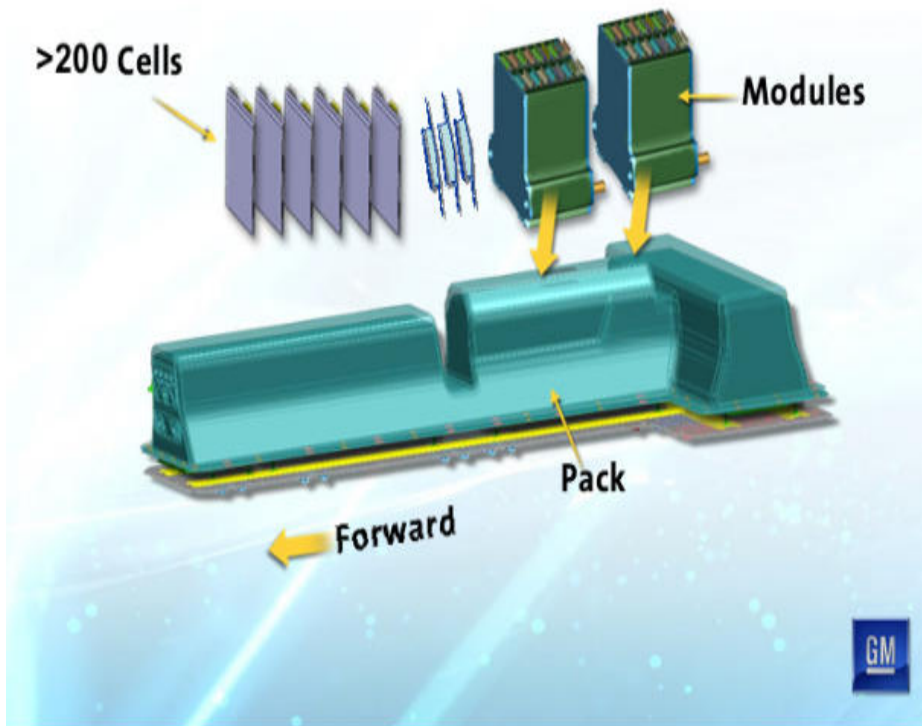


The heart of Voltec powertrain: Li-ion Battery



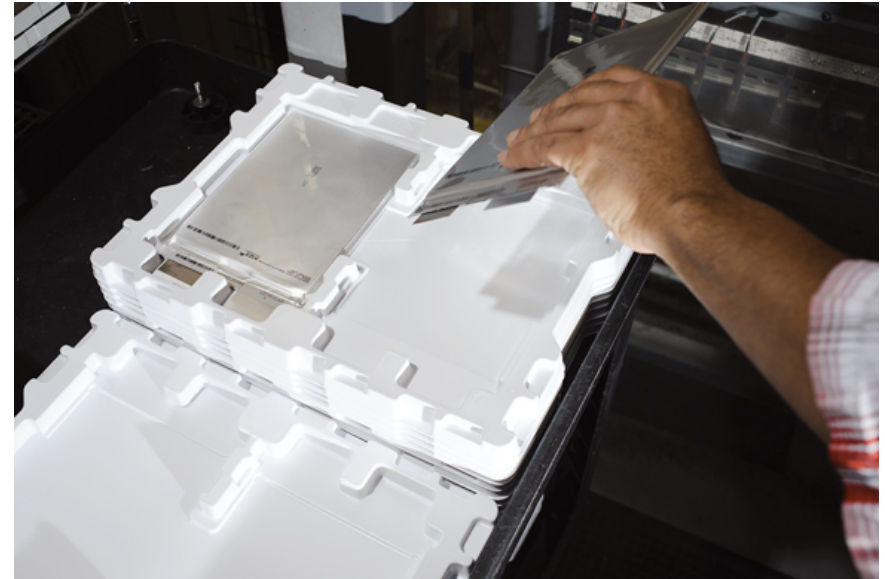
Voltec Battery Design

Battery Pack – Basic Construction



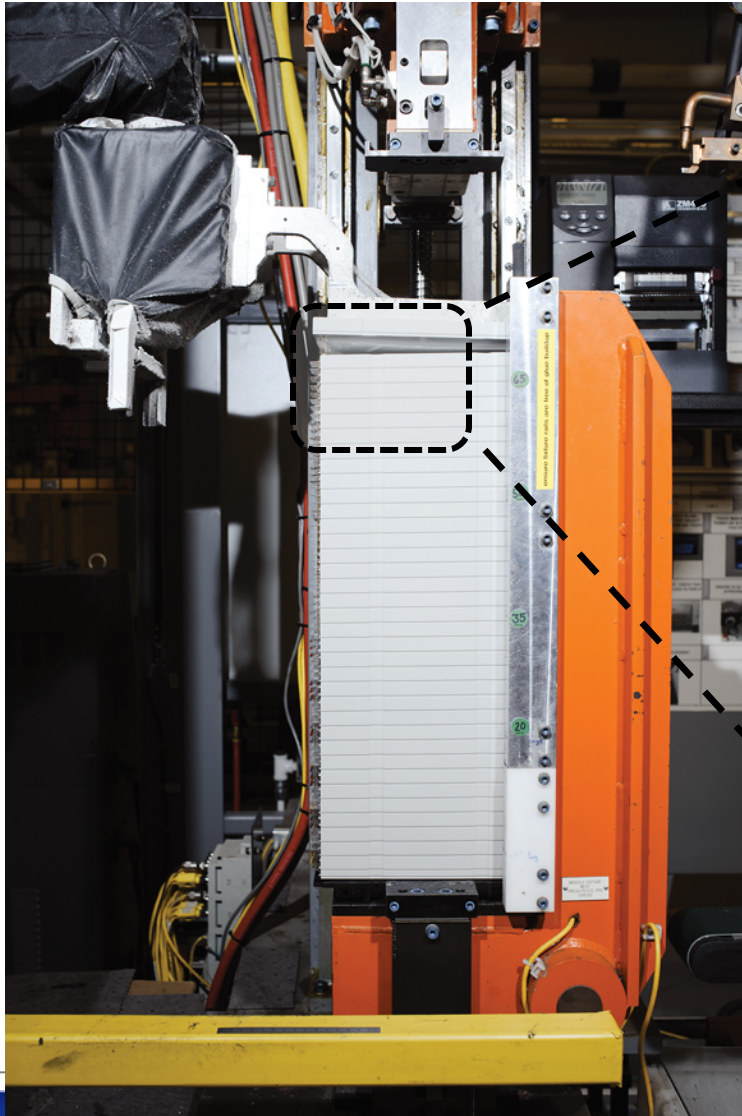
Battery Management System

Automotive Li-ion Battery “Cell”

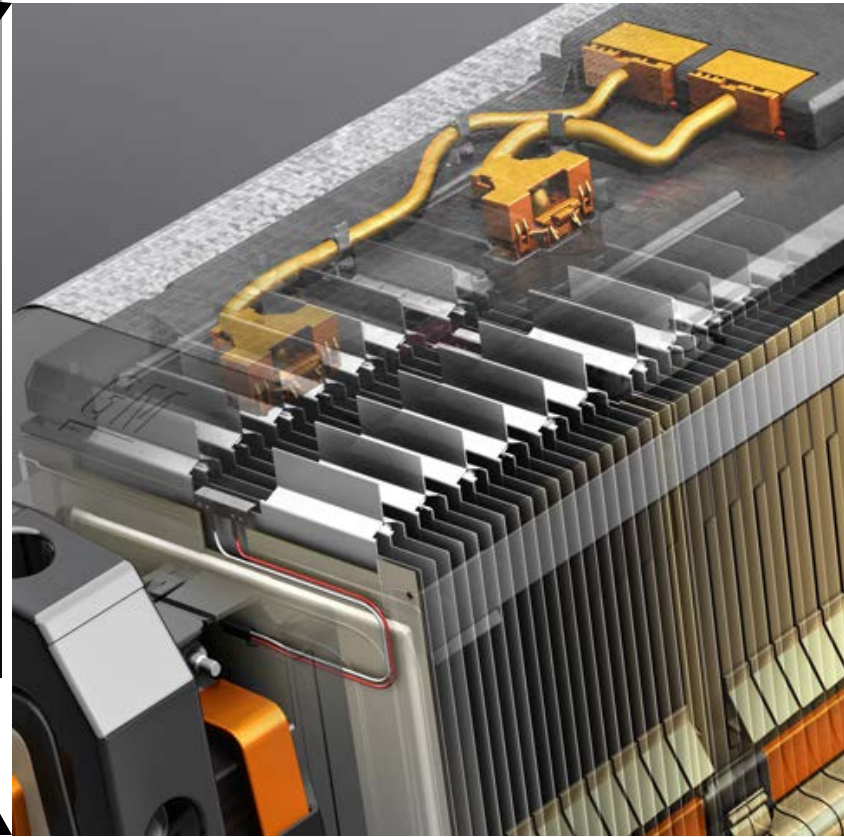


Courtesy MIT TechReview

Battery Assembly: Stacking Operation



Assembled Battery Pack



Installation of Interconnects



Ultrasonic Welding Is Used for Battery Assembly

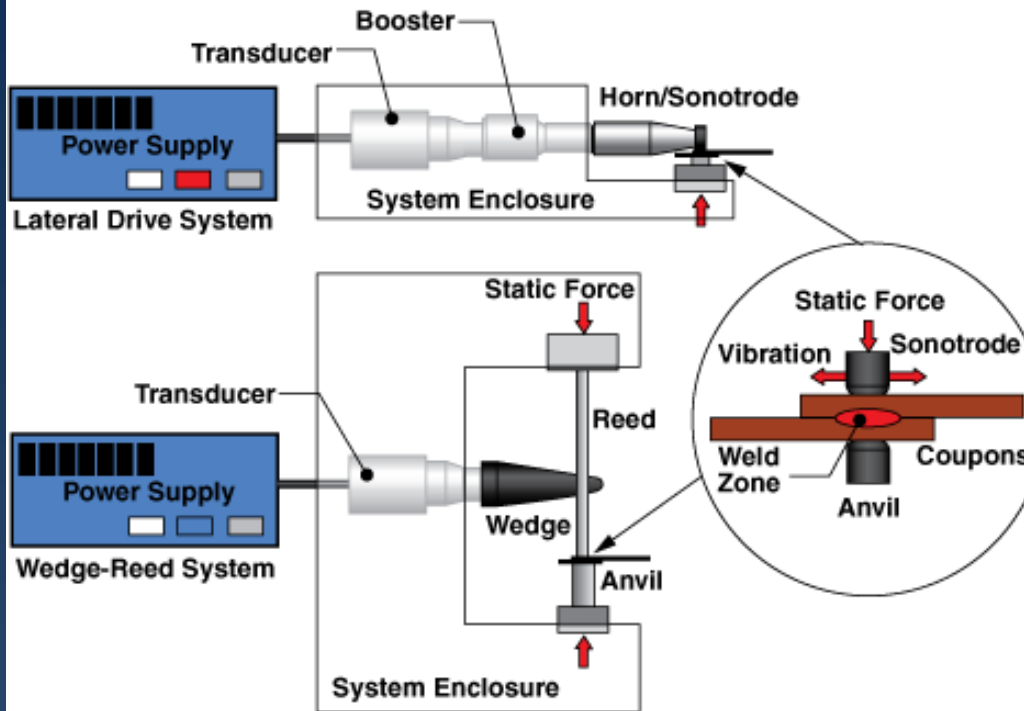


Photo courtesy of EWI



Voltec Battery Joints



Four parts (three cell tabs and a common bus) per joint, three interfaces, dissimilar metals: aluminum and copper.

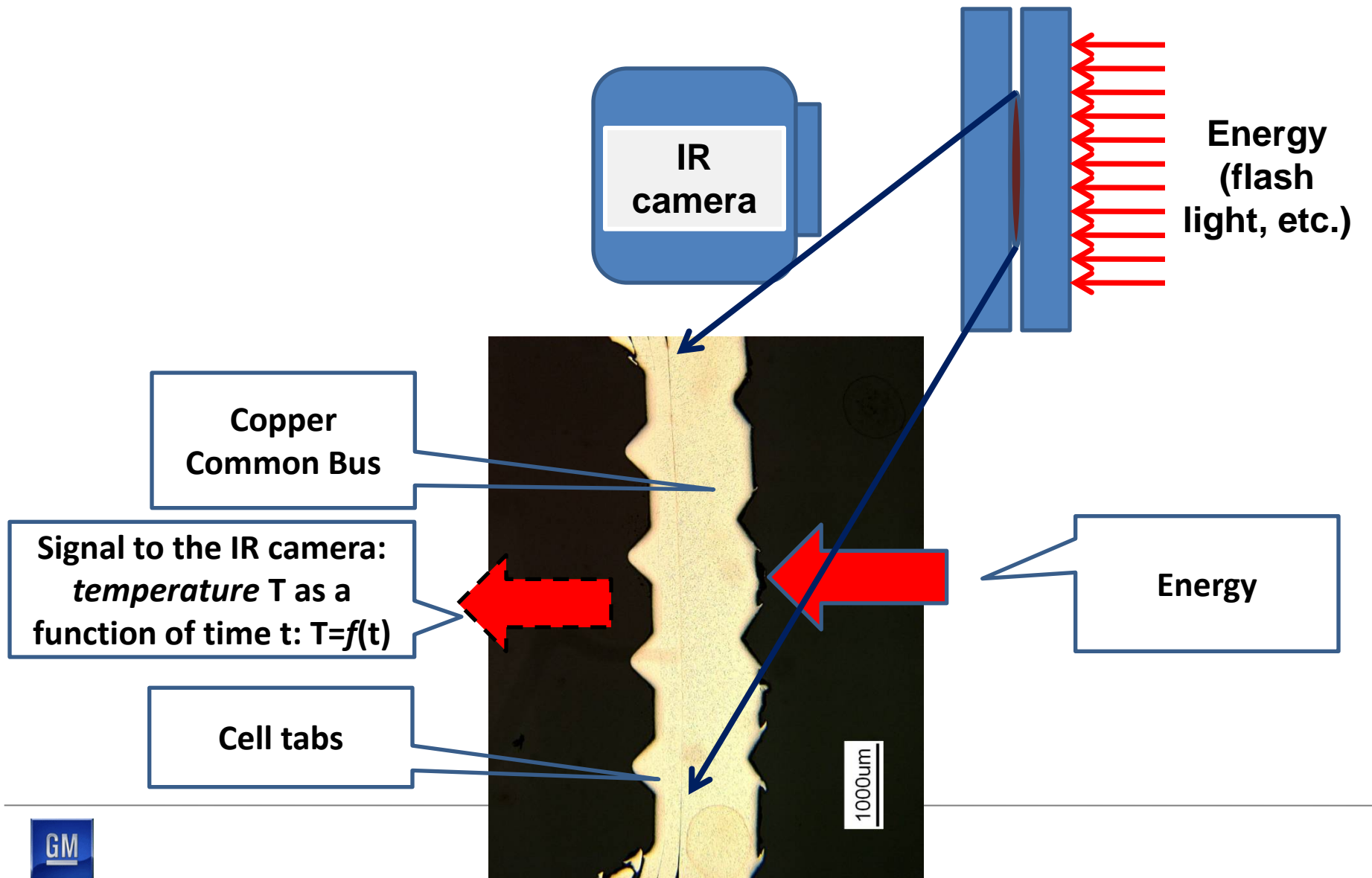
Each battery = 200 welds, multiple automated welding stations, high production rate.

Each interface has to be good!

Novel NDE Techniques Developed In-House

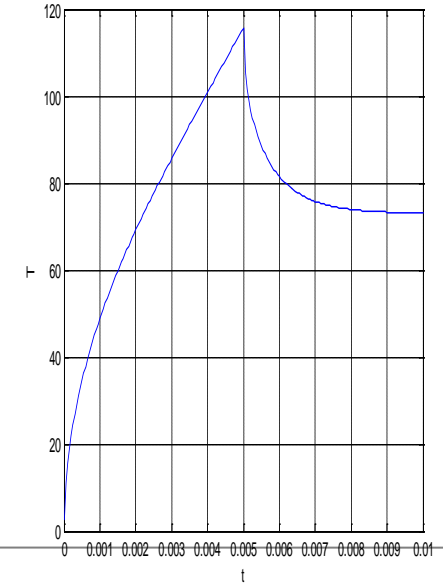
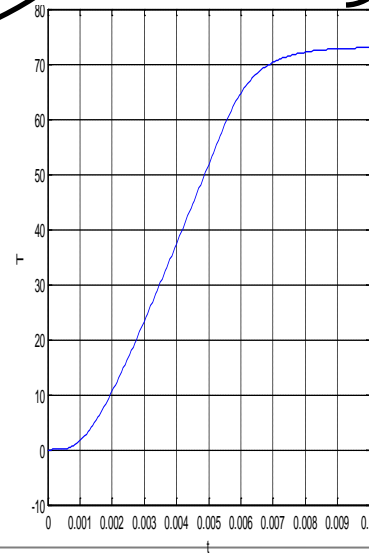
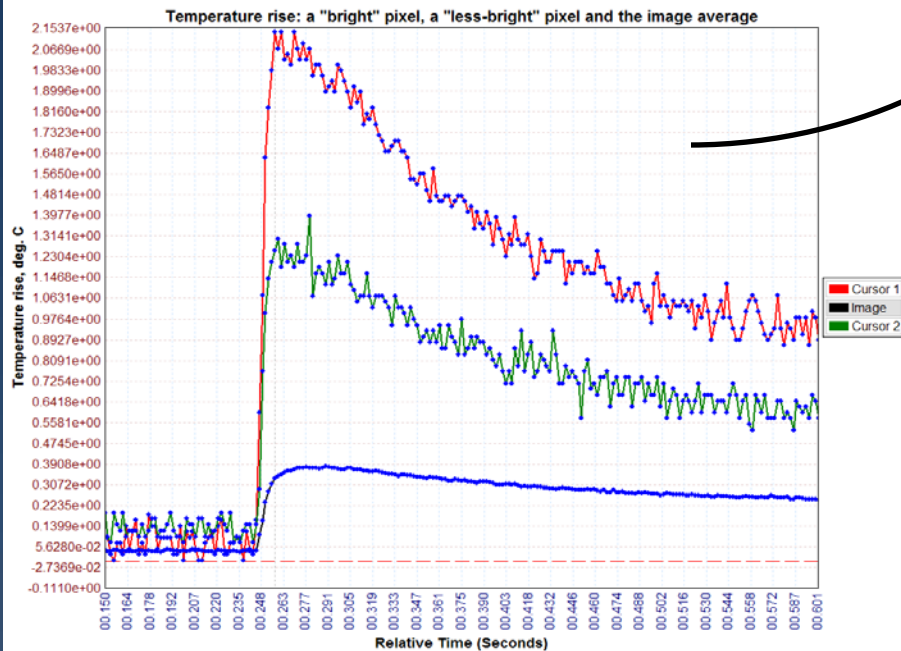
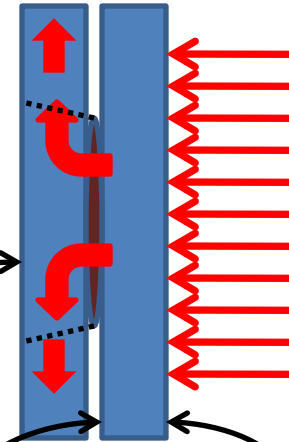
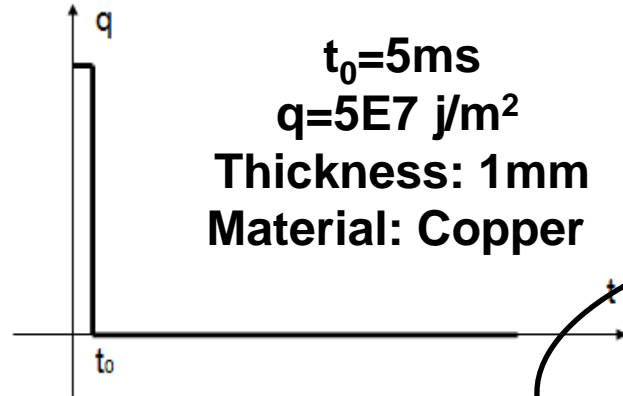
- **Active and Passive Flash Thermography NDE**
- **Shearographic NDE with Vibration Excitation**
 - Automated “pick test”;
 - Good in finding concealed defects; can detect the extend of weld fused area
- **High-precision electrical resistance NDE:**
 - Tests functionality of the weld *and* its strength
 - A large number of welds can be measured quickly (~0.2 sec per measurement) and conveniently with one fixture

Flash Thermography NDE

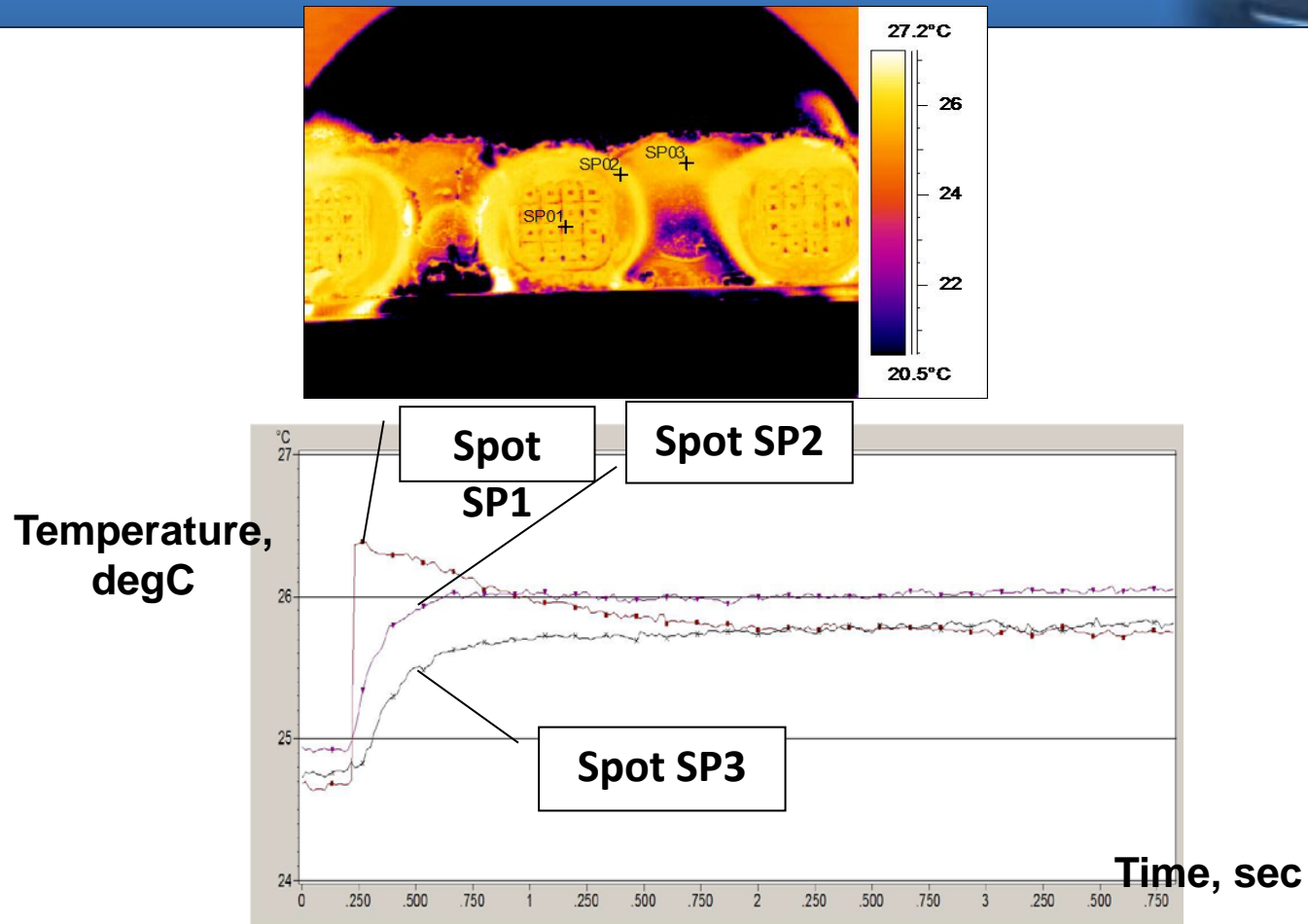


Thermal model

$$\begin{cases} \frac{\partial T}{\partial t} = a \frac{\partial^2 T}{\partial x^2} & (a = k / \rho c) \\ T|_{x=0} = 0 \\ \frac{\partial T}{\partial x}|_{x=0} = \begin{cases} q/k, & 0 \leq t \leq t_0 \\ 0, & t_0 \leq t \end{cases} \\ \frac{\partial T}{\partial x}|_{x=l} = 0 \end{cases}$$

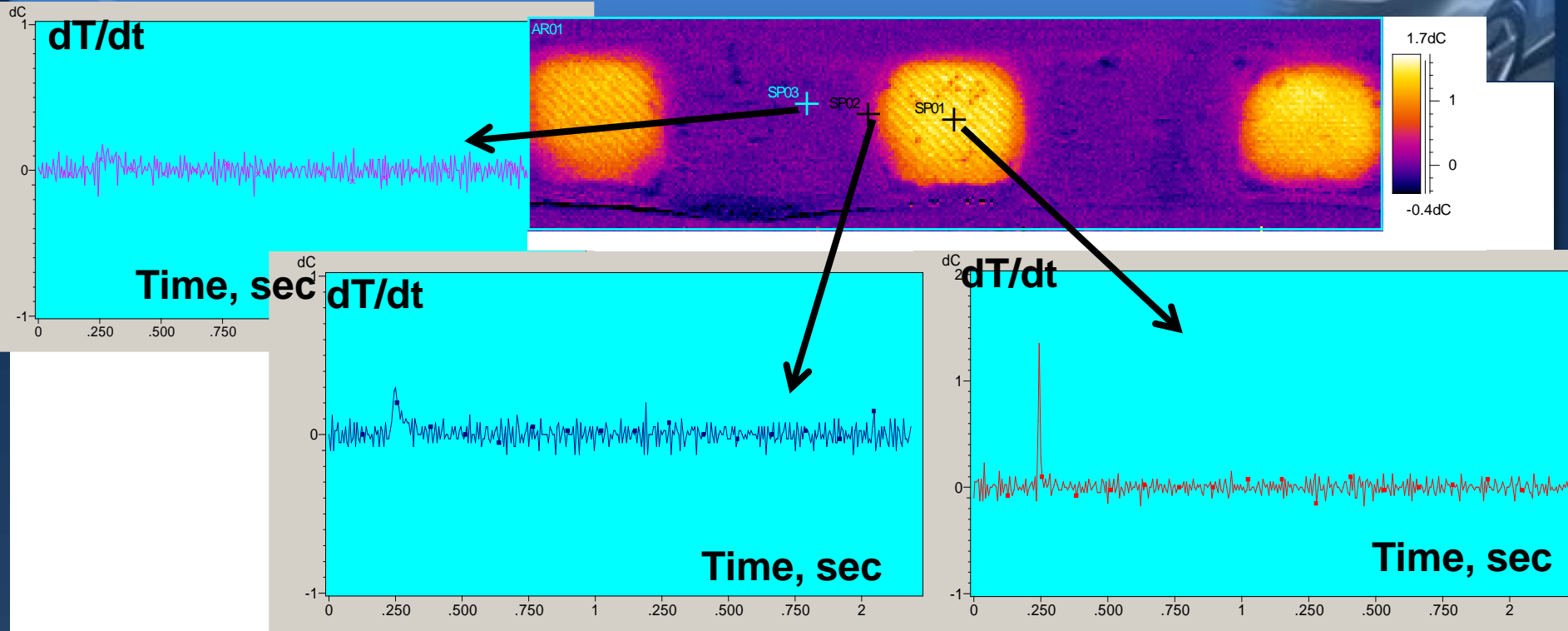


How to detect the fused area



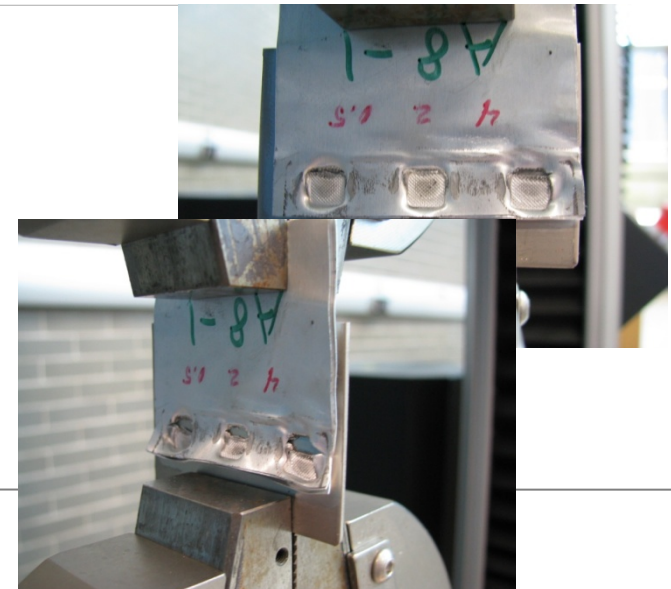
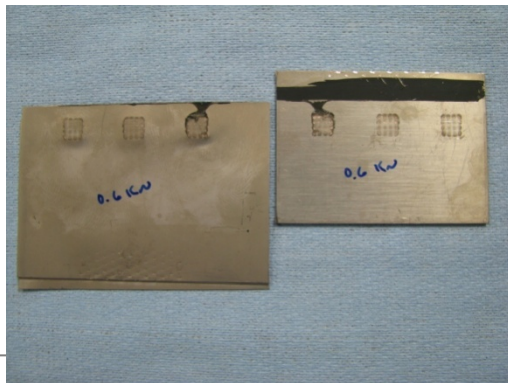
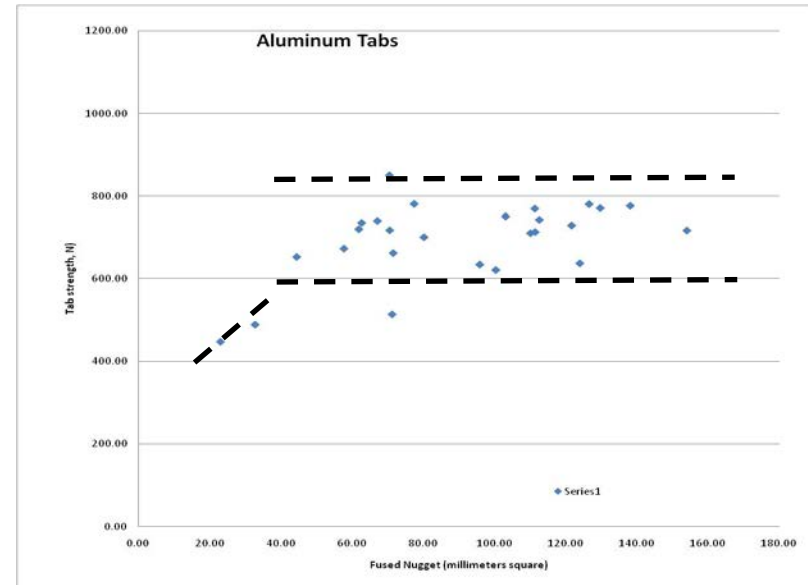
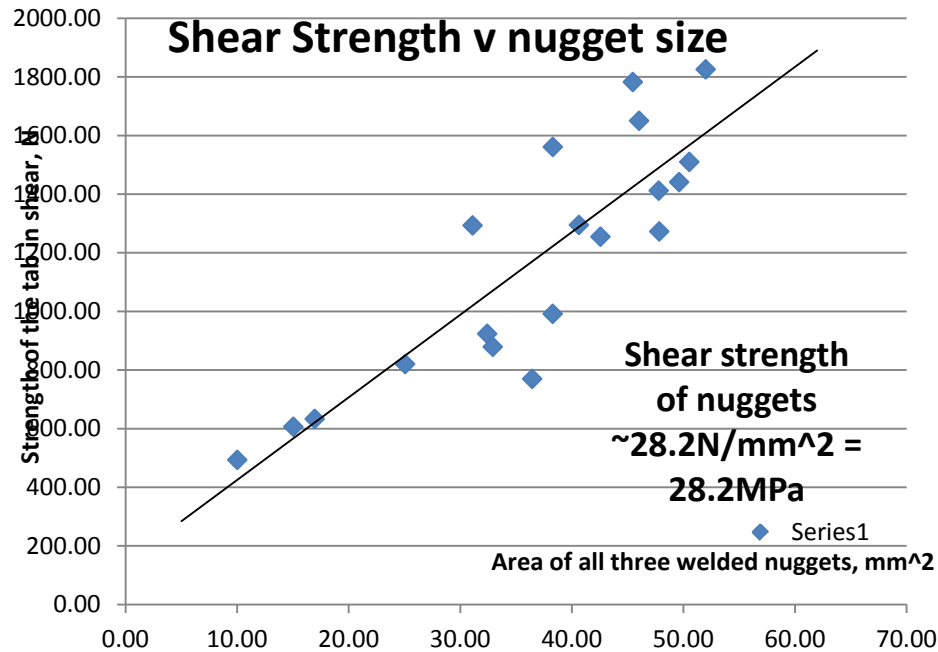
The temperature rise is more rapid in the fused area.

Results of differentiation with regard to time

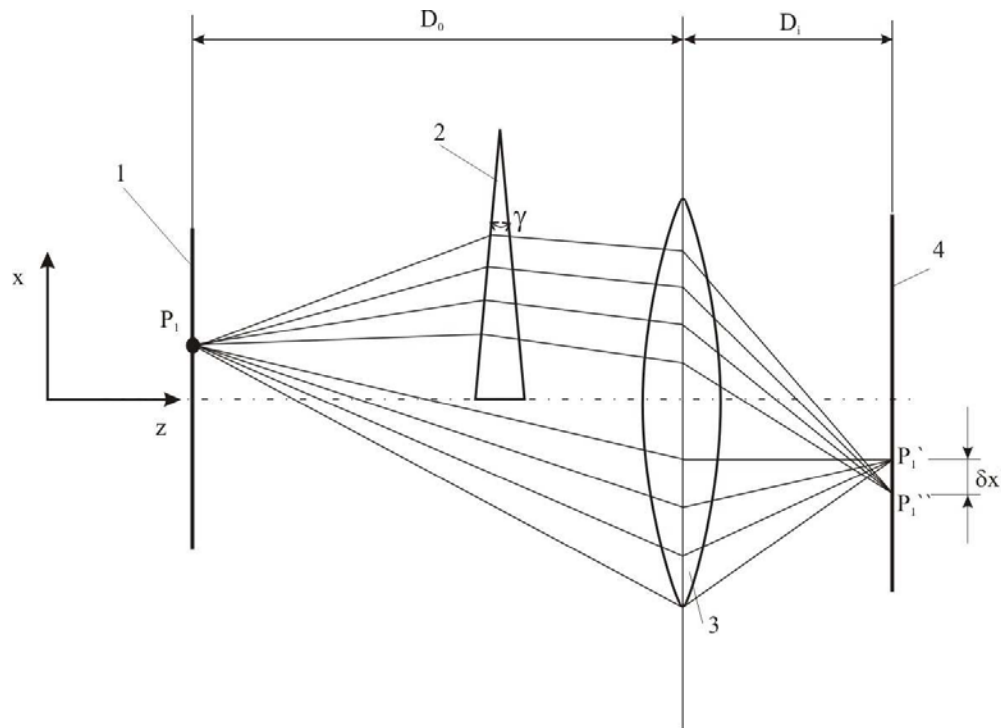


Post-processing: differentiating with respect to time in each point (pixel) to find total fused area.

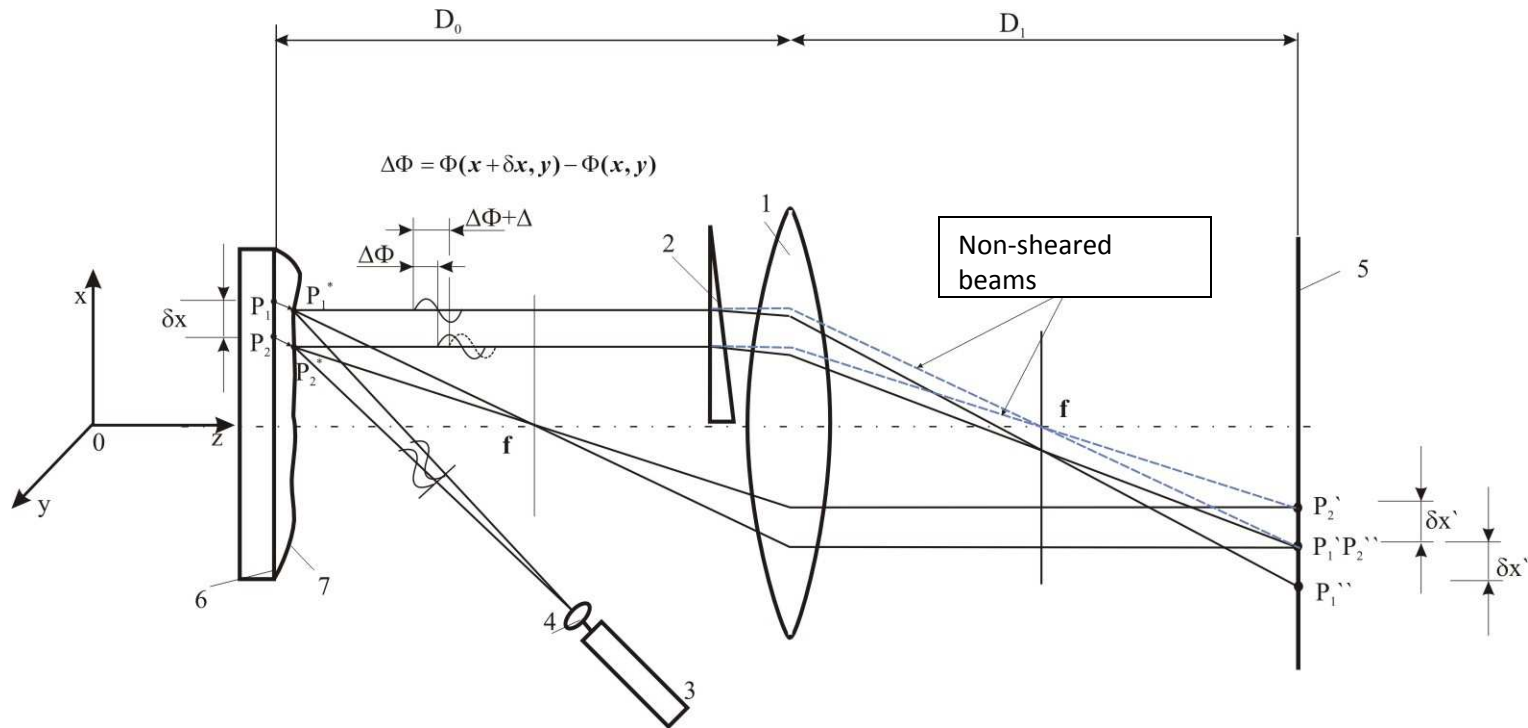
Weld strength correlates with the size of the “nugget” ...unless the joint fails elsewhere



What is a shearographic camera?



Formation of a shearographic pattern

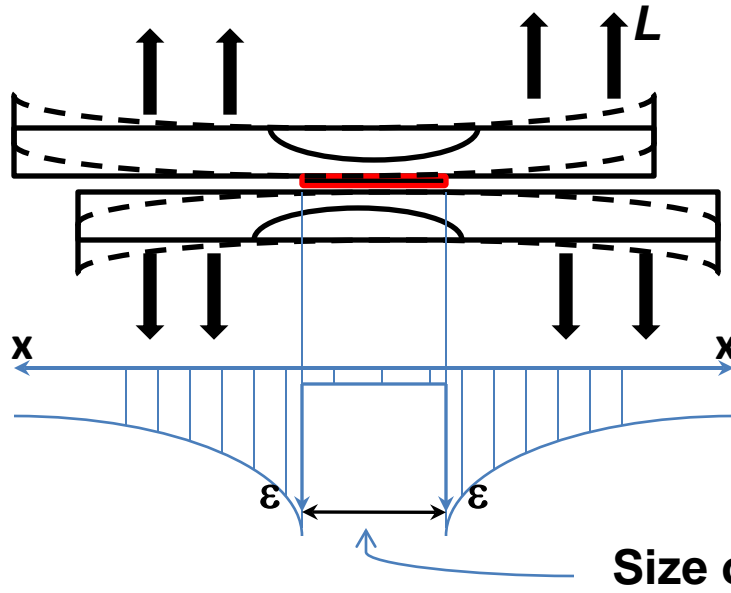


Two superimposed images are formed: a *sheared* image(s) of the object and the superimposed image of the fringes containing information about surface strains.

Shearography-based NDE with vibration excitation



- When vibration is applied to an assembly, a pattern of (elastic) strains forms around the weld



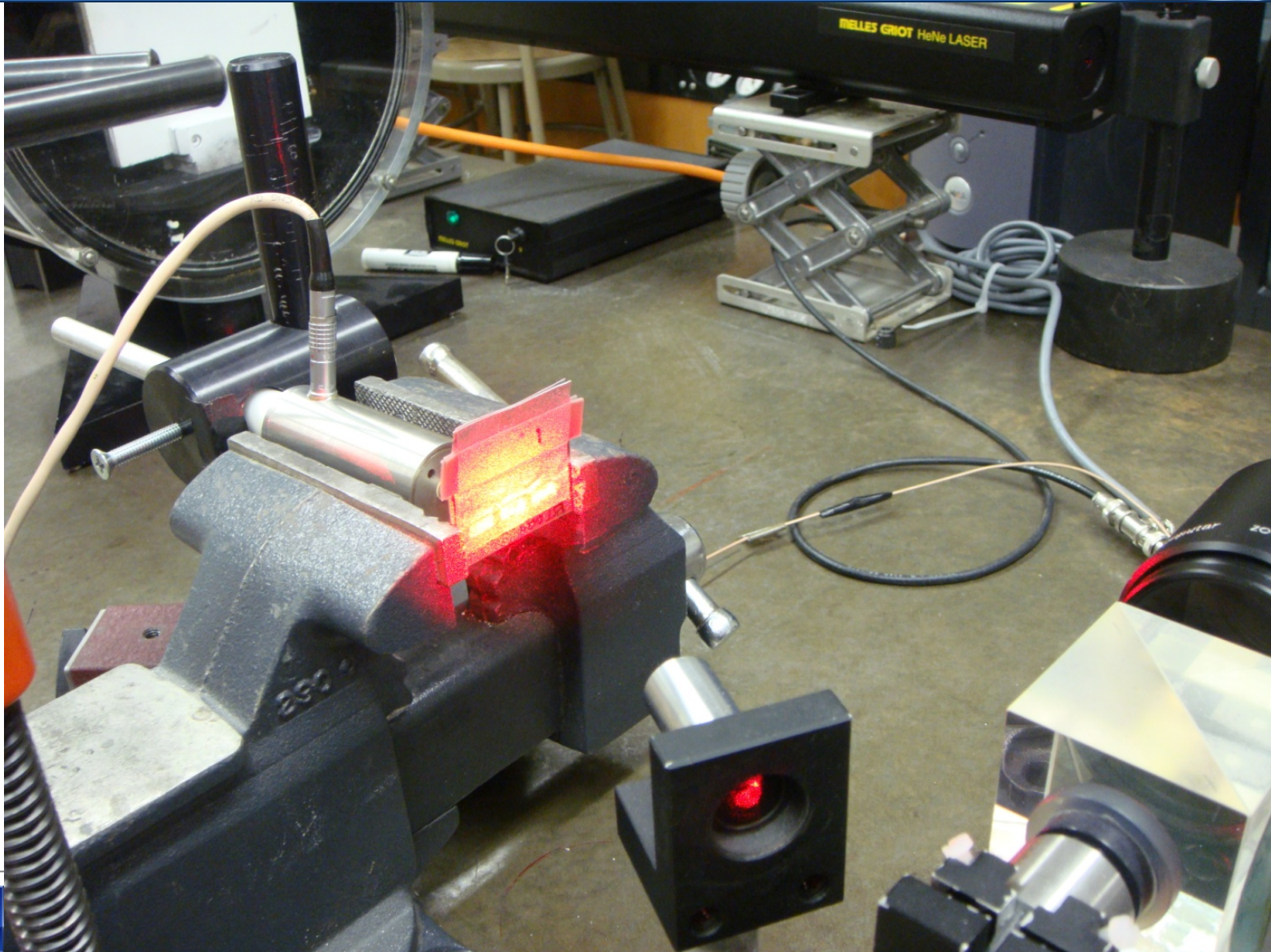
A schematic of a spot weld,
loaded with loads L

Pattern of strains ε (generally, a 3D
field, becomes 2D on the surface)

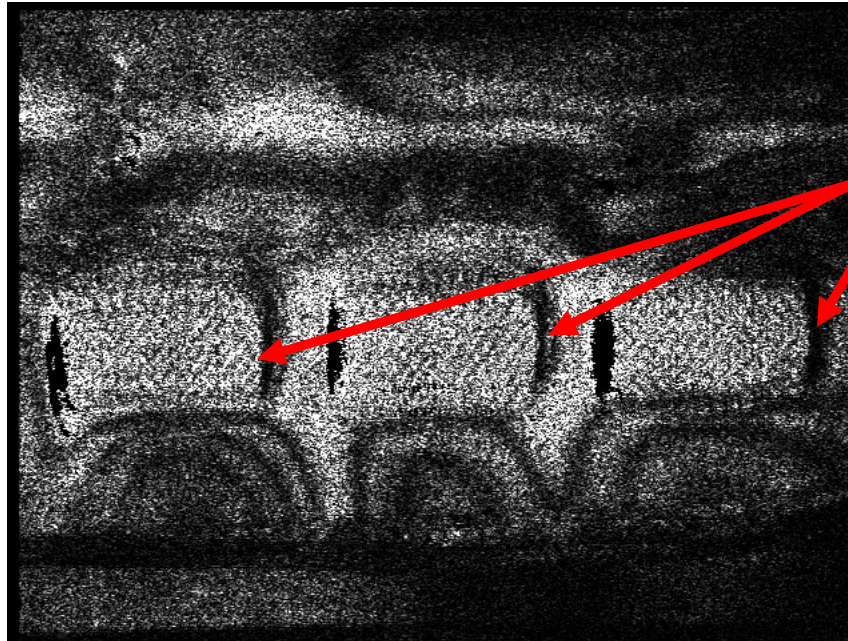
Size of the weld nugget

Image recognition is used to detect weld defects.
FEM model is used to determine the size of the fused area from the strain pattern (“inverse problem”).

Sample with three welds, illuminated by a laser

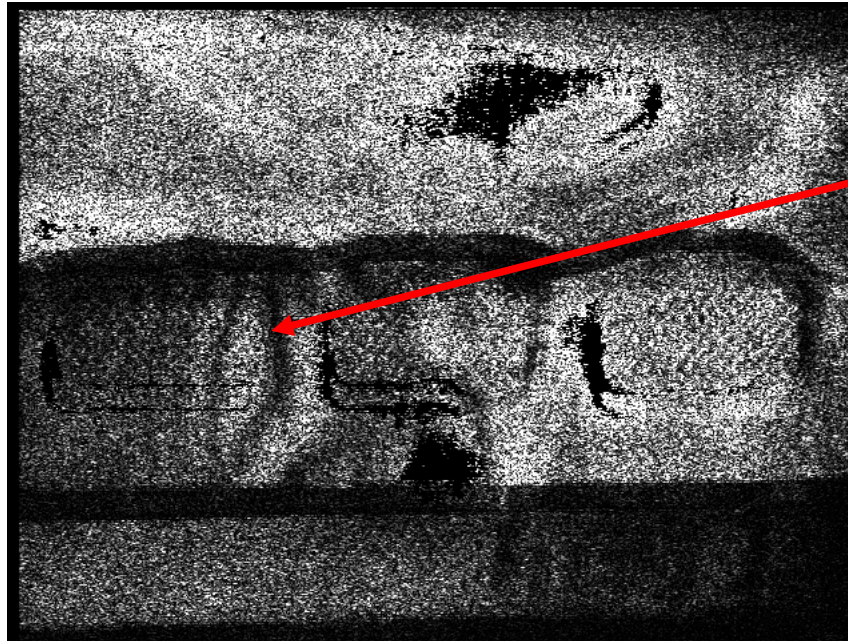


Good weld. Excitation frequency is 9.3KHz



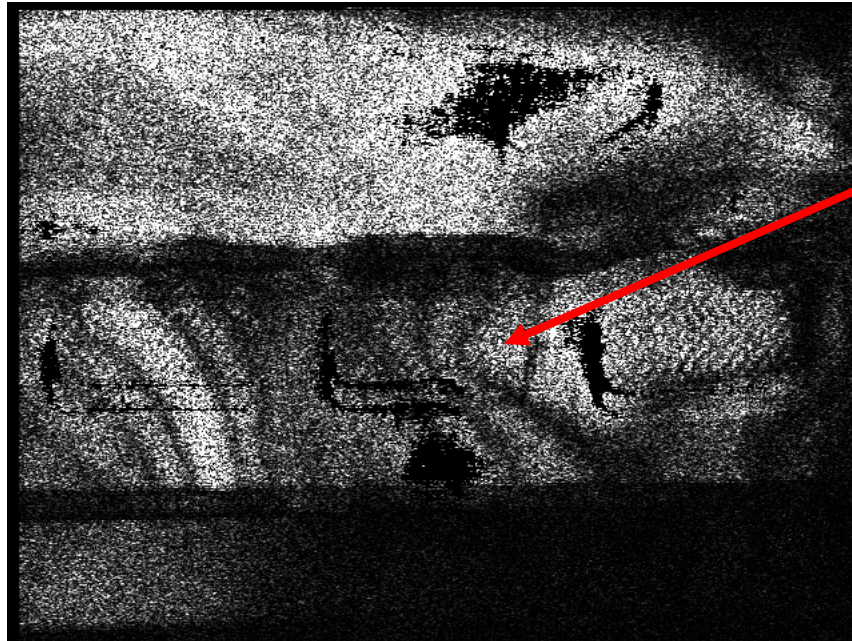
3 good welds.

Defective weld. Excitation frequency is 2.5KHz



No weld nugget

Defective weld. Excitation frequency is 5KHz



Partial weld

High-precision electrical resistance NDE



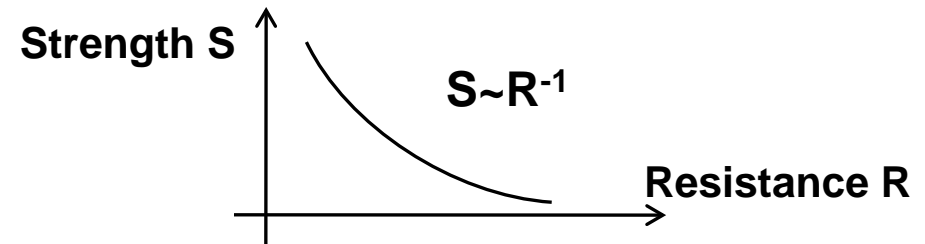
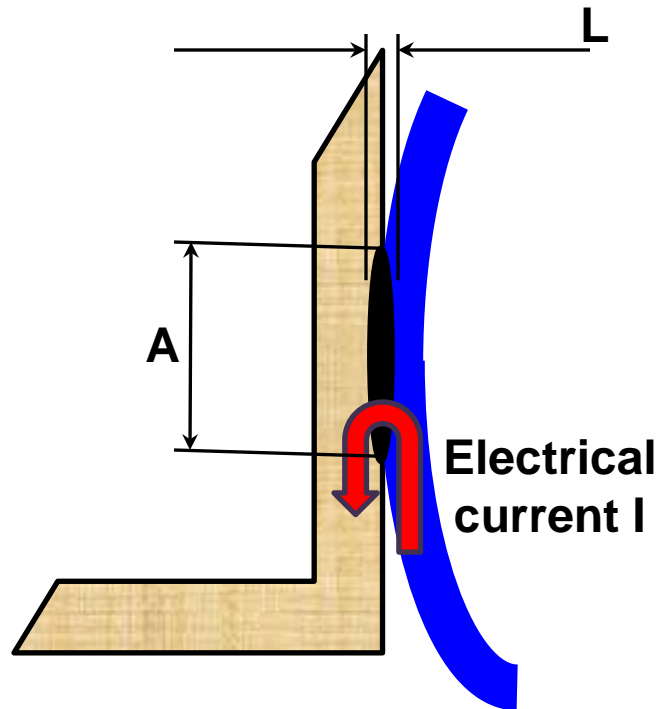
Electrical Resistance R and Strength S of a Weld:

- area A
- Resistivity ρ
- Interface “length” L
- Interface ultimate strength σ_u

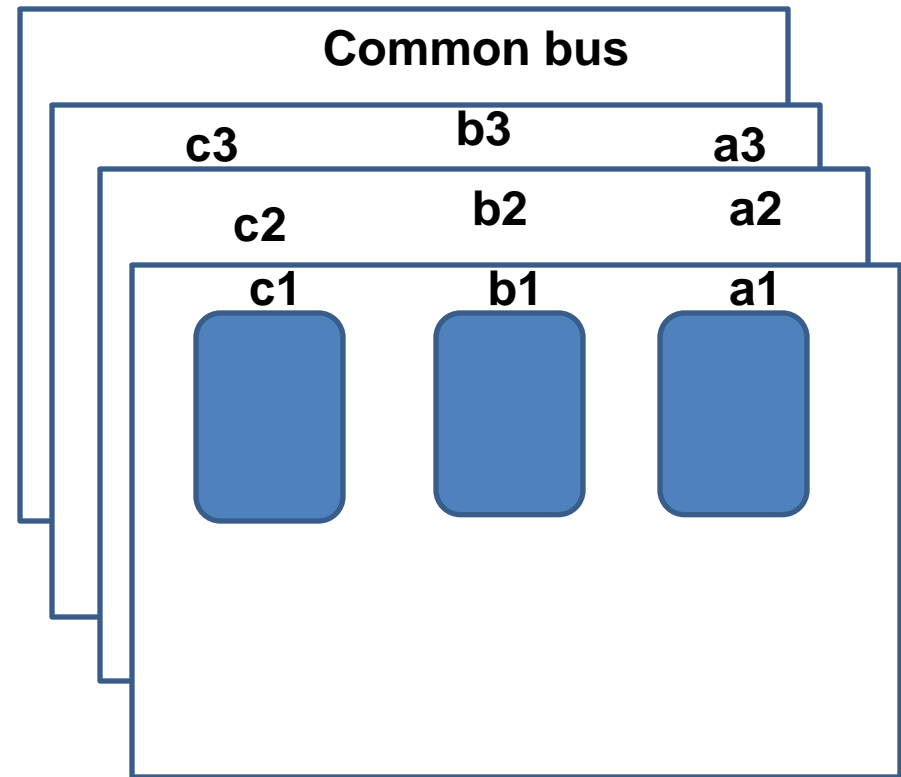
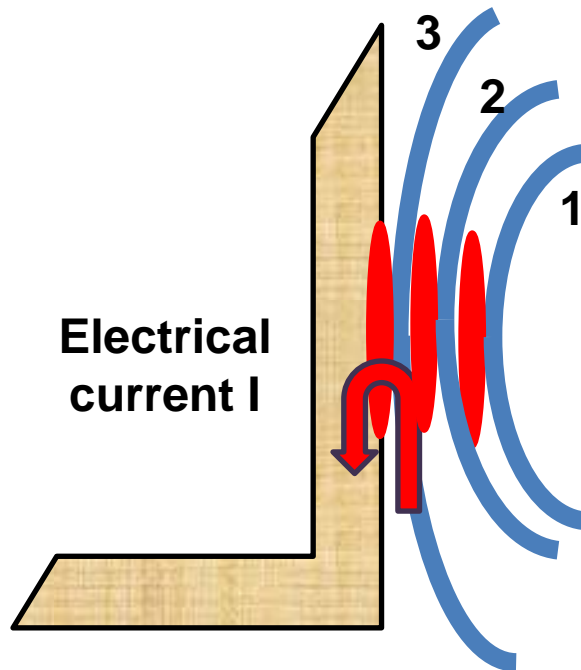
$$S = \sigma_u A$$

$$R = \rho \frac{L}{A}$$

$$\text{Therefore: } S \propto R^{-1}$$

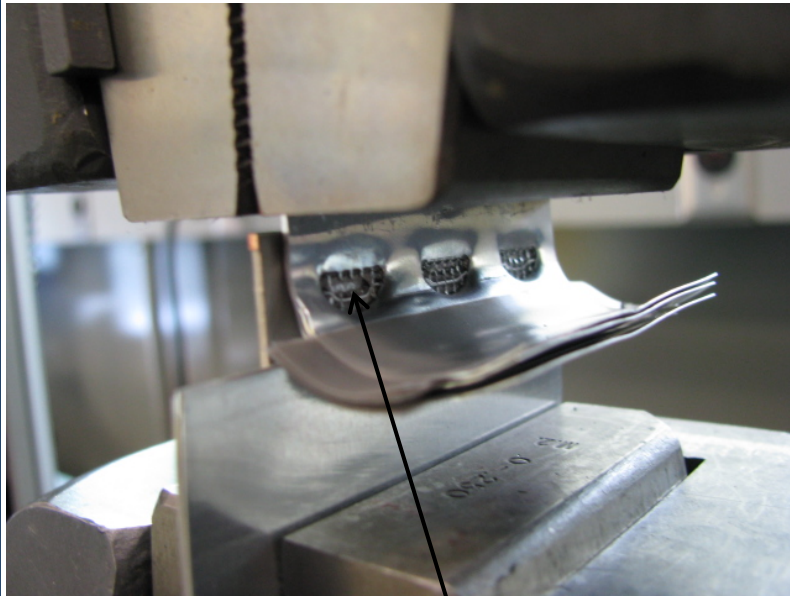


The real weld is more complicated...



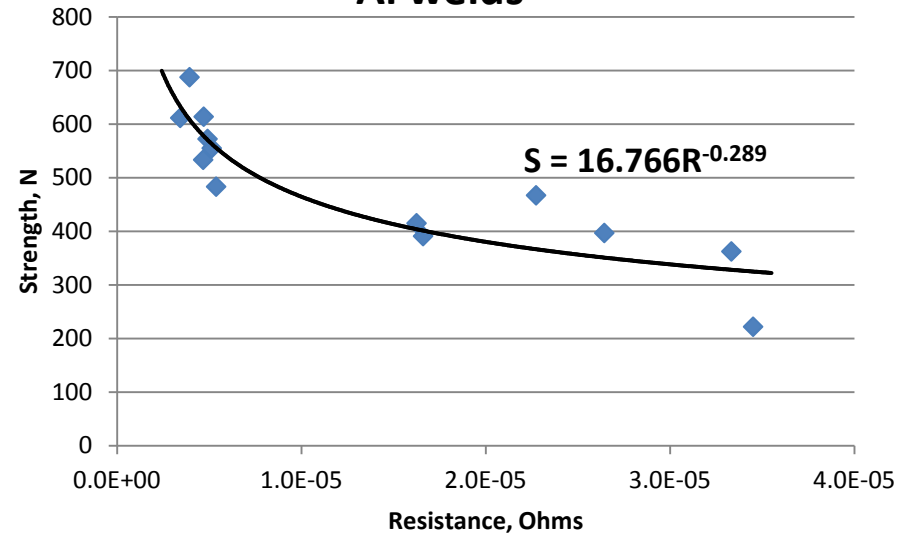
Correlation: Strength v Resistance

Strength testing of welded samples

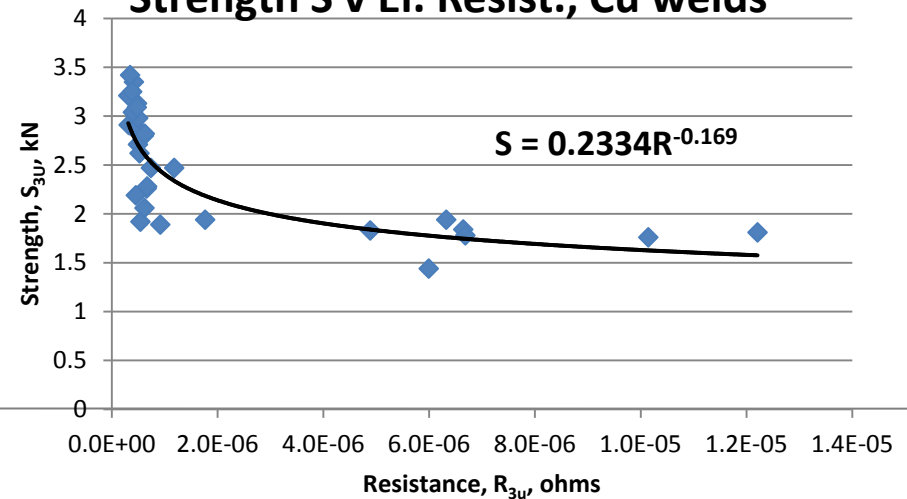


Tearing through the weld

Shear strength v El. resist., Al welds



Strength S v El. Resist., Cu welds



Comparison of the developed NDE methods

| Method | Advantages | Disadvantages |
|-------------------------------------|---|---|
| Thermography | The only method to measure the size of the fused area of multi-ply welds Non-contact | Requires high-power energy input → needs protection on production floor. |
| Shearography | Measures the true extent of a fused area; may uncover concealed defects | Requires: <ul style="list-style-type: none">•high-resolution shearographic cameras•sophisticated image analysis and software |
| Precision Electrical Resistance NDE | Measures the main functional parameter of the weld. Can monitor welds throughout the battery life. | Requires contact fixture; needs a reliable contact with joints |

Automotive NDE Needs



■ Traditional NDE areas:

- NDE of safety-critical lightweight automotive components
- NDE of welding and joining
- NDE of adhesive joints
- NDE of spot welds (in selective applications)

■ New NDE applications:

- NDE of Li-ion batteries and cells, in production and throughout the life
- Inexpensive NDE methods for composite materials
- NDE of joints of dissimilar materials, composites
- Life monitoring of composite structures.

■ Production process control



THANK YOU FOR YOUR ATTENTION!



BACKUP SLIDES



Automotive NDE Needs



■ Traditional NDE areas:

- NDE of safety-critical lightweight automotive components
- NDE of welding and joining, particular of dissimilar materials and composites
- NDE of adhesive joints

■ New NDE applications:

- NDE of Li-ion batteries and cells, in production and throughout the life
- Inexpensive NDE methods for composite materials
 - Infrared, shearography, vibro-thermography, x-ray, CT, ultrasonic, eddy current; combination, new NDE techniques
- Life monitoring of composite structures.
 - Fluorescent dyes/penetrants
 - Electrical methods

■ Process control in production

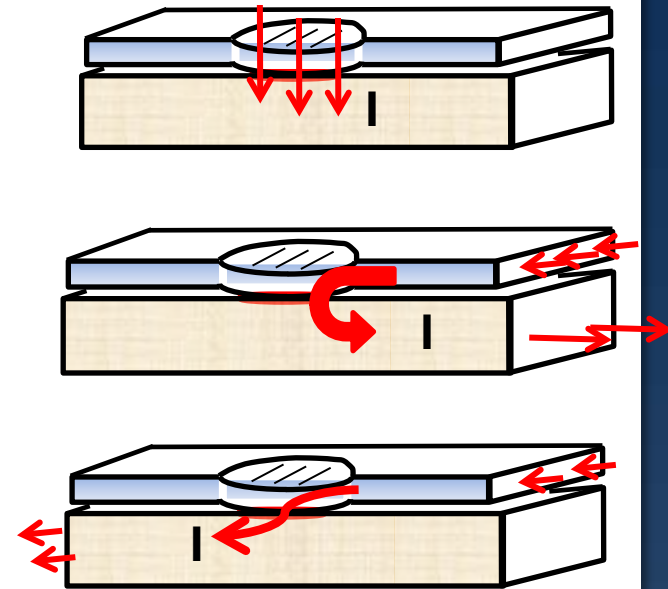
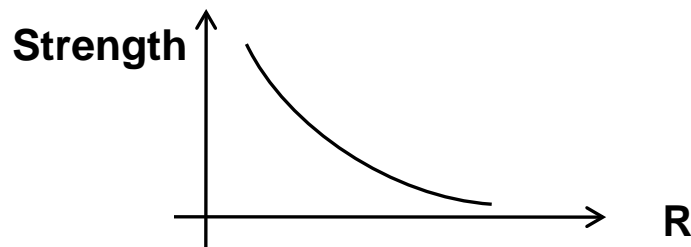
High-precision electrical resistance NDE

The electrical resistance of the weld depends on how the current is applied.

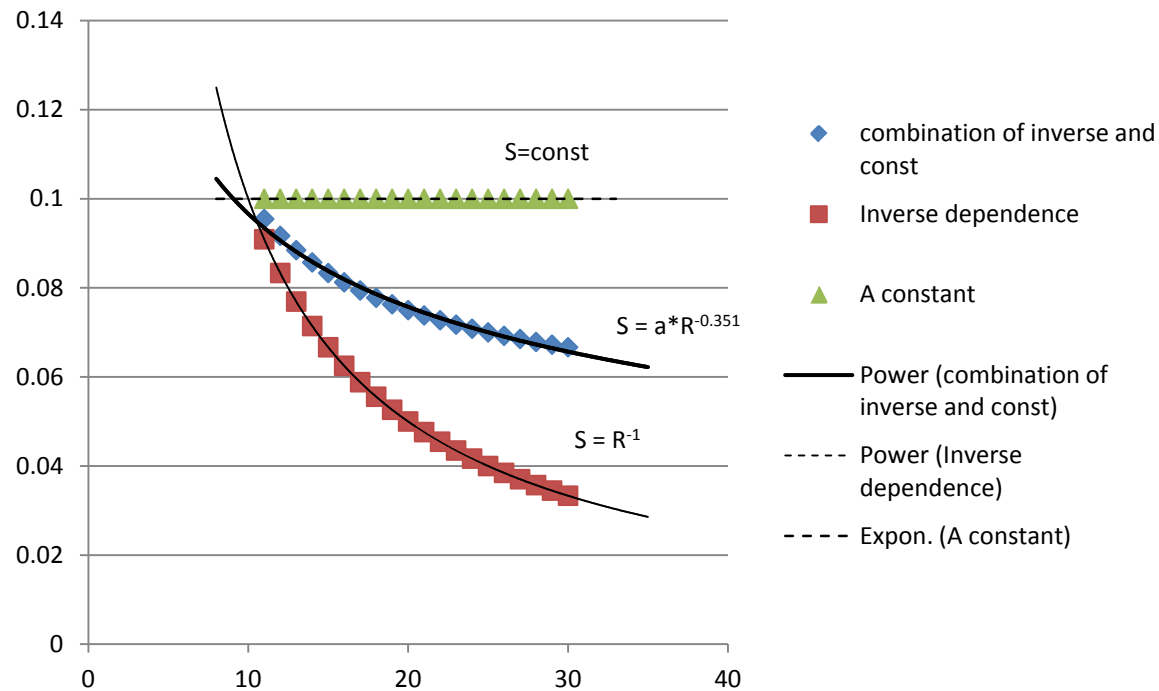
$$S = \sigma_u A$$

$$R = \rho \frac{L}{A}$$

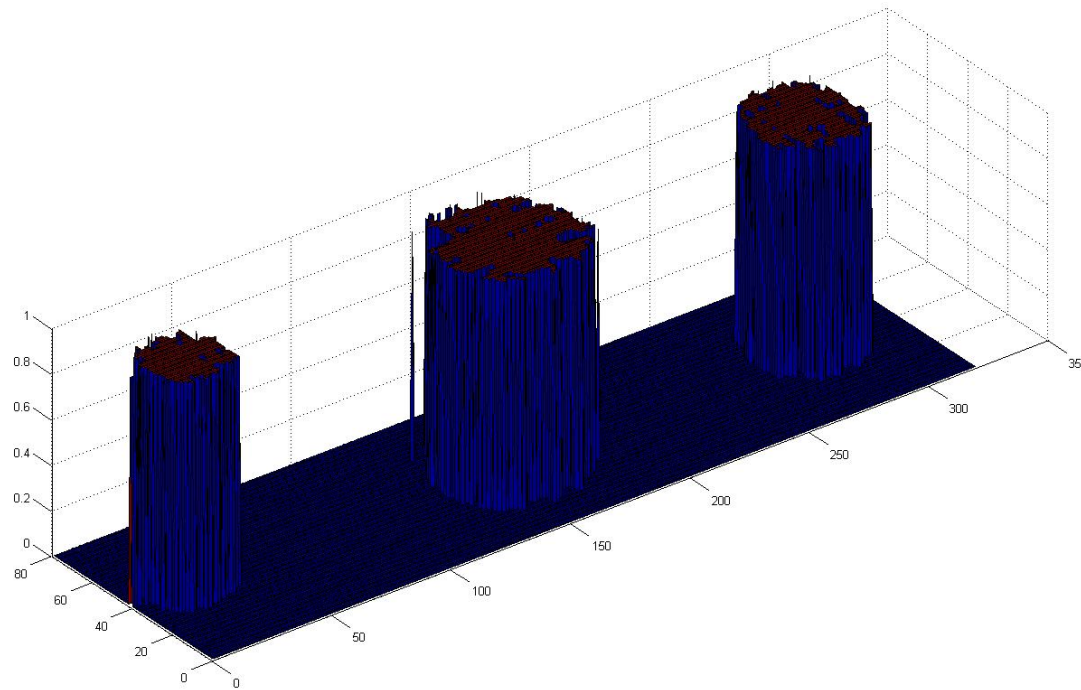
$$\text{Therefore: } S \propto R^{-1}$$



Explanation of lower power



The signal can be digitized (made 0 or 1) and counted



- Done with Matlab
- Each pixel is a square with dimensions (approximately):
 - $100\mu \times 100\mu$, with area $A=10^{-2} \text{ mm}^2$



- The entire module can fit in the field of view of IR camera...
- ...but heat can be applied one joint at a time

